**NANOTECHNOLOGY APPLICATIONS IN MEDICINE AND BEYOND**

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**NANOTECHNOLOGY**

Nanotechnology deals with conversion of individual atoms, molecules, or compounds into structures in the nanometer scale length (1-100 nm) and the creation of various types of nano materials and nano devices. It involves work from top down which involves reducing the size of large structures to smallest structure and bottom up which involves changing individual atoms into nanostructures. Nanotechnology has advanced in the field of medicine and biotechnology which has revolutionized the present century.

**Applications of Nanotechnology:**

Nanotechnology has varied applications in different fields like medicine, electronics, transportation, energy, agriculture, cosmetics, space exploration, biotechnology.

**I) Health and Medicine:**

Nano medicine will benefit early detection and prevention, diagnosis, treatment and follow-up of diseases

**Diagnosis:**

Gold nano particles when tagged with short segments of DNA can be used for detection of genetic sequence in a sample and also as biosensors.1

Carbon nano tubes (advanced biosensors) are used for cancer diagnosis

The Nano Chip System is used in electronically enhanced hybridization of complementary DNA strands in the fields of genomic diagnostics.

Microfluidics (lab-on-a chip) is the modern science of fluids on the nanometer scale.

Molecular cyto-genetics is now enhanced by use of biomedical nanotechnology, e.g., use of atomic force microscopy (AFM) and quantum dot (QD) FISH.

Nano- particles are use in gel-based and gel-free techniques, PCR and hybridization techniques

Nano particles are used as contrast in ultrasound and MRI.

**ROLE OF NANOTECHNOLOGY IN DIFFERENT CONDITIONS/ FIELDS:**

**A) Cancer:**

**Table 1: Uses of nanoparticles**

|  |  |
| --- | --- |
| Nanoparticles | Uses |
| Carbon nanotubes | Detection of DNA mutation, disease protein biomarker. |
| Dendrimers | Controlled release drug delivery, image contrast agents. |
| Nano crystals | Improved formulation for poorly-soluble drugs, labelling of breast cancer marker HeR2 surface of cancer cells. |
| Nano particles | MRI and ultrasound image contrast agents, targeted drug delivery |
| Nano shells | Tumor-specific imaging, deep tissue thermal ablation. |
| Nano wires | Disease protein biomarker detection, DNA mutation detection, gene expression detection. |
| Quantum dots | Optical detection of genes and proteins in cell assays, tumor and lymph node visualization |

Nano wires are used to prepare sensor test chips. They can detect proteins and other biomarkers left behind by cancer cells from patient’s blood. Nano particles, such as quantum dots used in conjunction with magnetic resonance imaging to produce exceptional images of tumor sites. Thus, the use of fluorescent quantum dots could produce a higher contrast image and at a lower cost than organic dyes.

**Treatment:**

Nano technology-based drug delivery is based upon three facts:

* Efficient encapsulation of the drugs
* Successful delivery of said drugs to the targeted region of the body
* Release of drug at target place

Kanzius RF therapy attaches microscopic nano particles to cancer cells and then "cooks" tumours inside the body with radio waves that heat only the nanoparticles and the adjacent (cancerous) cells.

Cadmium selenide nano particles in the form of quantum dots are used in detection of cancer tumours because when exposed to ultraviolet light, they glow. The surgeon injects these quantum dots into cancer tumors and can see the glowing tumor, thus the tumor can easily be removed.

Nano particles are used in cancer photodynamic therapy, wherein the particle is inserted within the tumor in the body and is illuminated with photo light from the outside.

**Drug delivery importance:** Nano particles transports drug molecules to the desired location which reduces the drug consumption and treatment expenses. The pharmacokinetics and bio-distribution of the drug are altered leading to increased efficiency and prevention of resistance by avoid the body's defence mechanisms. Tissue damage can be prevented. Larger clearance of drug from body can be reduced.

Abraxane, is albumin bound paclitaxel, a nano particle is used for treatment of breast cancer and non-small- cell lung cancer (NSCLC). 2

Carbon nano particles with hydrophobic paclitaxel is for head and neck cancer.

Polyethylene glycol (PEG) nano particles carrying payload of antibiotics at its core is beneficial for bacterial infection.

The minicells are the membranes of mutant bacteria loaded with paclitaxel and coated with cetuximab, antibodies used for treatment of a variety of cancers.

Nano sponges due to their small size and porous nature can bind poorly-soluble drugs within their matrix and improve their bioavailability.3

Iron-oxide nano spheres with doxorubicin-loaded liposome treat breast cancer cells.

**B) Stem cell research:**

Stem cells are isolated and grouped by magnetic nanoparticles (MNPs).

Molecular imaging and tracing of stem cells are done by quantum dots.

Carbon nano tubes, fluorescent CNTs and fluorescent MNPs are used for delivery of gene or drugs into stem cells.

Proliferation and differentiation of stem cells are regulated by designed unique nano structures.

Nanotechnology speeds up the development of stem cells in the field of regenerative medicine and leads to stem cell-based therapeutics for the prevention, diagnosis and treatment of human diseases.4

**Figure 1: Nanoparticles in stem cells**

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**C) Neurodegenerative disorders:**

Nano carriers such as dendrimers, nano gels, nano emulsions, liposomes, polymeric nano particles, solid lipid nano particles and nano suspensions transport medicines through BBB by endocytosis and/or transcytosis by improving their BBB permeability and reducing their neurotoxicity. They are used for the management of CNS conditions such as, Alzheimer's disease, brain tumors, HIV encephalopathy and acute ischemic stroke.5

**Alzheimer's disease:**

Nano particles (NPs) have high affinity for the circulating amyloid-*β* (A*β*) forms and therefore may induce “sink effect” and improve the AD condition.

Ultrasensitive NP-based bio-barcodes and immune sensors, scanning tunnelling microscopy procedures are capable of detecting A*β*1−40 and A*β*1−42.

**Figure 2: Nanoparticles in Alzheimer’s disease**



**Parkinson's disease:**

Nano particles provide neuro protection and/or a permissive environment and active signalling cues for guided axon growth.

Intracranial nano-enabled scaffold device (NESD) is used for the site-specific delivery of dopamine to the brain

Peptides and peptidic nano particles are newer tools for various CNS diseases.

**D) Tuberculosis:**

Novel antibiotics can be designed to overcome drug resistance, cut short the duration of the treatment course and to reduce drug interactions with antiretroviral therapies.

The advancements in nano-based drug delivery systems for encapsulation and release of anti-TB drugs can lead to development of a more effective and affordable TB pharmacotherapy.

**E) Cardiovascular disease:**

Biodegradable nano particle aggregates coated with tissue plasminogen activator, tPA, were injected intravenously. They dissolve clots in the arterial wall which improves blood flow in the affected area and reduces internal bleeding

**F) Operative dentistry:**

Nano filled composite resin materials are believed to offer excellent wear resistance, strength, and ultimate aesthetics due to their exceptional polish ability and lustre retention. Nano fillers constitute spherical silicon dioxide (SiO2). Micro hybrid composites with additional load of nano fillers are the best choice in operative dentistry as they mimic enamel and dentin.6

**G) Ophthalmology:**

Nano -particles are used for the following conditions:

* Treatment of oxidative stress; measurement of intraocular pressure
* Treatment of choroidal new vessels
* Prevention of scars after glaucoma surgery
* Treatment of retinal degenerative disease using gene therapy
* Prosthetics
* Regenerative nano medicine
* Drug delivery
* Microemulsions, nanosuspensions, nanoparticles, liposomes, niosomes, dendrimers and cyclodextrins in the field of ocular drug delivery
* Novel nanoscale-dispersed eye ointment (NDEO) for the treatment of severe evaporative dry eye.7
* The excipients used as semisolid lipids were petrolatum and lanolin, as used in conventional eye ointment, which were coupled with medium-chain triglycerides (MCT) as a liquid lipid; both phases were then dispersed in polyvinyl pyrrolidone solution to form nano dispersion.

**H) Surgery:**

Gold-coated nano shells weld the artery perfectly. So can be useful in cardiovascular surgeries. Nano-surgery is done with precision and without visible damage to the cell.8

**I) Visualization:**

Drug distribution and its metabolism can be determined by tracking movement. Luminescent tags were used to dye various numbers of cells. These tags are quantum dots attached to proteins which penetrate cell membranes.

**J) Antibiotic resistance:**

Zinc oxide nano particles can decrease the antibiotic resistance and enhance the antibacterial activity of ciprofloxacin against microorganism.

**K) Immune response:**

The nano device bucky balls have been used to alter the allergy/ immune response. They prevent mast cells from releasing histamine into the blood and tissues**.** These bind to free radicals.

**L) Orthopedics:**

Nano- materials are used to make bone implants which offer more strength and stability and have less antigenic response.

**II) Food:**

Nanotechnology helps in the food industry by:

Qualitative and quantitative production of healthier, safer, and high-quality functional foods.

Increased shelf life of food products, preventing contamination and production of enhanced food quality.

Enhance the food bioavailability, taste, texture, and consistency.9

**Table 2: Commercial nanofood products and their applications**

|  |  |  |  |
| --- | --- | --- | --- |
| **Product name** | **Type of product** | **Nanomaterial** | **Application** |
| Nutra Leaseanola Active oil | Food and beverage | Nanosized self-assembled liquid  structures (NSSL) | Inhibits transportation of cholesterol from the digestive system into the bloodstream. 10 |
| Nanotea | Beverage | Nanoselenium | Good supplement of selenium |
| Fortified Fruit Juice | Health drink | Micelles 5–100 nm in diameter | Increased Lycopene |

**Table 3: List of nanomaterial-based biosensors with their application in food science and food nanotechnology**

|  |  |  |
| --- | --- | --- |
| **Nanomaterials** | **Analyte** | **Samples** |
| Silicon dioxide | Act as food colorant, hygroscopic, anticaking, and drying agent. | Food preservation and packaging |
| Silver zeolite | Antimicrobial agent | Preservations, disinfectors, and decontaminants |
| Carbon nanotubes | Optical, electrical, mechanical, and thermal  conductivity | Food inspection and vacuum proof food packaging |

**Table 4: Different types of nano formulations and their applications in food industries**

|  |  |  |  |
| --- | --- | --- | --- |
| **Nanostructured materials** | **Nanoparticles** | **Methods** | **Applications** |
| Low-density lipoproteins | Fish oil | Microencapsulation | Food additives—mask odour of tuna fish oil |
| Biopolymers (proteins or polysaccharides) | Micelles | Microemulsions | Produce glycerides in food products |
| Biodegradable biopolymeric NPs | Polylactic acid | Encapsulation | Encapsulate and deliver drugs, vaccines, and proteins |

**Table 5: Utilization of nanoparticles in nutraceuticals and pharmaceuticals with their applications:**

|  |  |
| --- | --- |
| **Nutraceuticals** | |
| **Nanoparticles** | **Applications** |
| Nanoliposomes | Specific delivery of nutraceuticals.11 |
| Nanoselenium | Green tea helps in uptake of selenium |
| Nanocapsules | Improve bioavailability of nutraceuticals (cooking oils) |
| **Pharmaceuticals** | |
| **Nanoparticles** | **Applications** |
| Cellulose nanocrystal composite | Drug carrier |
| Metallic nanoparticles | Enhanced radiotherapy and highly sensitive diagnosis. |
| Nanocrystals quantum dots | Multiple color imaging of liver. Labelling of breast cancer marker, HeR 2 surface of cancer cells.12 |

**III) Agriculture:**

Nanotechnology regulates and modifies the metabolism in crops, provides a larger specific surface area to herbicides, fertilizers, and pesticides and ensure their ‘on-demand’ release. It promotes controlled and targeted nutrient delivery, resulting in enhanced crop growth and development. Mesoporous silica NPs (MSNs), carbon nanotubes (CNTs), quantum dots (QDs), magnetic NPs (MNPs), metallic NPs, and metal oxide NPs are some of the nano- particles used in agriculture.13

**Table 6: Ameliorative effects of NMs on abiotic stress in crops.14**

|  |  |  |  |
| --- | --- | --- | --- |
| **Abiotic stress** | **Nanomaterials** | **Plant species** | **Ameliorative effects** |
| Heat | TiO2 NPs | Tomato | Enhanced photosynthesis, regulated energy dissipation, and induced stomatal opening |
| Cold | ZnO NPs | Rice | Alleviated chilling stress by regulating the chilling response transcription factors |
| Salinity | Fe2O3 NPs | Wheat | Improved the growth of both root and shoot |
| Drought | CeO2 NPs | Soybean | Enhanced growth, development, and yield |
| Heavy metal | Au NPs | Rice | Suppressed Cd uptake and alleviated Cd toxicity |

**IV) Cosmetics:**

Nanotechnology has both advantages and disadvantages in cosmetics. Targeted delivery, increased stability, efficacy, dermal penetration are some advantages while cost, inflammation, DNA damage are some disadvantages. Some may be teratogenic in nature due to easy placental penetration.15

**Table 7: Use of nanoparticles in cosmetics:16,17**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| S. No | Nanomaterial | Advantage | Disadvantage | Uniqueness | Type of Cosmeceutical |
| 1. | Silica | Hydrophilic, decreased manufacturing cost | Pulmonary toxicity | Used as filler | Lipstick |
| 2. | Inorganic particles (TiO2, ZnO) | Hydrophilic, biocompatible | Pulmonary toxicity | Absorb/ reflect UV light | Sunscreen |
| 3. | Carbon black | Light weight, increased chemical and thermal stability | Cytotoxicity, alters the phagocytic property of macrophages | Color pigment | Facemask, Mascara |

**V) Biotechnology:**

Nanotechnology has various applications in the field of biotechnology. Nanobiotechnology is used in drug discovery, drug delivery, molecular diagnostic, pharmaceutical development.

**VI) Military:**

Nano- materials suits detect damage (corrosion, substrate integrity, etc.) and prevent from environmental conditions (radiation, chemicals, temperature, gases, strain). Nanostructured coatings systems have been developed with the continuous ability to decontaminate a surface exposed to biological agents including spores Nano- particles provide better information and signal processing, autonomy and intelligence. Self-replicating smart nanorobots (SSN) can be used as a bio-weapon.

**VII) Energy and environment:**

Nanotechnology can be used for less expensive energy production and for renewal energies, in solar technology, nano-catalysis, fuel cells and hydrogen technology. Carbon nano tube fuel cells are used for storage of hydrogen, thus finds application in power cars. Nanotechnology helps in developing new ecofriendly and green technologies that can minimize undesirable pollution. Solid state lightening can reduce total electricity consumption.

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